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Using Field-Metered Data to Quantify Annual Energy Use of Portable Air Conditioners

Authors

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

DEFINITIONS OF ACRONYMS AND TERMS

AEU	annual energy use
AHAM	Association of Home Appliance Manufacturers
Btu/hr	British thermal units per hour
CEC	California Energy Commission
CER	cooling efficiency ratio
csv	comma-separated value
EER	energy efficiency ratio
LBNL	Lawrence Berkeley National Laboratory
PAC	portable air conditioner
RH	relative humidity
T/RH	ambient temperature and relative humidity

1 INTRODUCTION

As many regions of the United States experience rising temperatures, consumers have come to rely increasingly on cooling appliances (including portable air conditioners) to provide a comfortable indoor temperature. Home occupants sometimes use a portable air conditioner (PAC) to maintain a desired indoor temperature in a single room or enclosed space. Although PACs in residential use are few compared to centrally installed and room air conditioning (AC) units, the past few years have witnessed an increase of PACs use throughout the United States. There is, however, little information and few research projects focused on the energy consumption and performance of PACs, particularly studies that collect information from field applications of PACs. The operation and energy consumption of PACs may differ among geographic locations and households, because of variations in cooling load, frequency, duration of use, and other user-selected settings. In addition, the performance of building envelope (thermal mass and air leakage) as well as inter-zonal mixing within the building would substantially influence the ability to control and maintain desirable indoor thermal conditions. Lawrence Berkeley National Laboratory (LBNL) conducted an initial field-metering study aimed at increasing the knowledge and data related to PAC operation and energy consumption in the United States.

LBNL performed its field-metering study from mid-April to late October 2014. The study, which monitored 19 sites in the Northeastern United States (4 in upstate New York and 15 near Philadelphia), collected real-time data on PAC energy consumption along with information regarding housing characteristics, consumer behavior, and environmental conditions that were expected to affect PAC performance. Given the limited number of test sites, this study was not intended to be statistically representative of PAC users in the United States but rather to understand the system response to the cooling demand and to some extent, the operating hours of the studied units. Specifically, the primary objectives of the field-metering study were to (1) expand knowledge of the installation, energy consumption profiles, consumer patterns of use, and environmental parameters related to PAC use; (2) develop distributions of hours of PAC operation for three operating modes: standby,[1] fan-only, and cooling; and (3) describe how individual consumers' selection of PAC capacity, the area of the space to be cooled, the temperature set point, and environmental conditions affect energy use. Beginning to understand the energy consumption of PACs operating in American homes and commercial settings will help develop a more accurate energy use profile that characterizes relevant variables.

This report on LBNL's field-metering study of PAC energy use describes:

- a general definition of a PAC and how it operates (section 2);
- current practices and sources of data for estimating PAC energy use (section 3);

[1] For this project, off-cycle mode could not be clearly distinguished from standby mode because of the power measurement resolution.

- the process LBNL used to select field-metering sites, along with characteristics of the sites and the PACs studied (section 4);
- data collection methods and instrumentation (section 5);
- analysis methods (section 6);
- results and discussion (section 7); and
- conclusions (section 8)

2 DEFINITION AND OPERATION

PACs are assumed to be used:

- in homes in Northern climates that lack central cooling,
- where a window-style room AC is impractical, or
- as supplemental cooling where the central cooling system is inadequate.

A PAC may be used to achieve and maintain a desired temperature range in the space depending on the area of the space to be conditioned and the difference between the ambient temperature and the PAC's temperature set point. Some PACs include options for operating the unit as a dehumidifier and/or heater, with heating provided either by an electric resistance heater or by operating the unit as a heat pump. Although most units are intended for residential applications, certain PACs are used in light commercial settings.

2.1 Definition

PACs are self-contained, refrigeration-based products that are similar to room ACs. The unit removes latent and sensible heat from the ambient air in a single enclosed space. A PAC is not installed permanently in a wall or window. Instead a PAC is often used where window configurations or building regulations prevent installation of a room AC through the wall or window. Other than one or two ducts connected to a window, PACs require no major component installation.

Almost all PACs are air cooled, containing a compressor, cooling coils (as evaporator), heating coils, a fan, thermostat, and condensate pump or a bucket to remove excess moisture accumulated from the room or outdoor air (some models have the feature to evaporate the condensate). PACs generally have plastic enclosures, weigh 50 to 90 pounds, are between 28 and 36 inches tall, and are mounted on wheels to provide mobility. They typically operate on 120-volt power supply and are marketed to have cooling capacities of 7,000 to 14,000 British thermal units per hour (Btu/hr).

2.2 Operation

The three modes of operation of a PAC are:

1. Cooling mode (when both the fan and compressor are running and the PAC is fully operational),
2. Fan-only mode (when the fan is running, but the compressor is not), and
3. Standby mode (when the PAC is plugged in but not operating).

When operating in cooling mode, a PAC draws in warm ambient air from an enclosed space (room), passes it over an evaporator (cooling coils), and then discharges the conditioned air directly back to the room. Assuming that the PAC is set to cool the room, the air returned is slightly cooler (and drier) than when it entered the PAC. After the room reaches the temperature set point, the PAC automatically cycles on and off to maintain that set point. PACs are equipped with one or two plastic and flexible ducts/hoses (ducts) for handling the warm exhaust air from the condenser side of the unit. The unit comes with a kit to attach the ends of the duct(s) in a window, in an opening in a sliding door or a wall, or up through a drop ceiling. Units having one hose (single-duct PACs) draw in air from the room and exhaust the heat from the condenser air to the outside. This operation can create negative pressure in the room, resulting in a certain amount of infiltration of air from the outside or another adjacent space. Units having two hoses (dual-duct PACs) use one hose to draw in outside air and use the second hose to exhaust heat to the outside. Dual-duct units also draw some amount of air from within the space, leading to infiltration air (although typically less than for single-duct units). Depending from where the air infiltration related to single-duct operation comes, it may be less efficient than a dual-duct design. One manufacturer claims that a dual-duct PAC can cool a room as much as 40 percent faster and at a higher efficiency than a single-duct design.[2]

3 ENERGY USE INFORMATION AND CALCULATIONS

As mentioned previously, information regarding PAC energy use, usage patterns, and users' set point preference are almost non-existent. This study attempts to fill this knowledge gap. The following sections describe (1) current methods used to estimate annual energy use (AEU) of PACs; (2) data regarding capacity, hours and modes of operation, and rated energy efficiency, all of which affect energy consumption; and (3) sources of existing data consulted during LBNL's field study.

3.1 Current Practice for Estimating Annual Energy Use

Estimates of PAC energy consumption using rated (test) conditions rely on four variables: capacity, hours, modes of operation, and energy efficiency. The AEU of a PAC is calculated by multiplying the unit's capacity by the number of hours it operates in each mode (cooling, fan, and standby), then dividing that result by the unit's energy efficiency. The calculation typically is used in developing manufacturers' engineering estimates. The following equation is used to

[2] See *Friedrich Portable Air Conditioners*. http://www.friedrich.com/portable-air-conditioning/. Last accessed December 7, 2014.

derive the AEU of a PAC based on estimates of power consumption and assumptions regarding hours of use.

$$PAC_{ENERGY} = \left(\frac{TotalHoursofUse}{Year}\right) \times \left[\left(\frac{CAP \times X_{Cool}}{Eff \times \left(\frac{1}{1000}\right)}\right) + \left(X_{Fan} \times kW_{Fan}\right) + \left(X_{Stby} \times kW_{Stby}\right)\right]$$

Where:

PAC_{ENERGY}	=	annual energy use of PAC (kWh/year),
$\frac{TotalHoursofUse}{Year}$	=	number of hours the PAC is used per year (at >0 watts [W]),
CAP	=	PAC capacity (Btu/hr),
X_{Cool}	=	fraction of time in cooling mode,
Eff	=	PAC efficiency (Btu/hr per W),
X_{Fan}	=	fraction of time in fan-only mode,
kW_{Fan}	=	power use of fan-only mode (kW),
X_{Stby}	=	fraction of time in standby/off mode, and
kW_{Stby}	=	power use of standby/off mode (kW).

The prediction of AEU is generally based on assumptions of fraction of time and power consumption. However, this is imprecise because the unit operation is governed by the user settings, such as control mode and set point, as well as the ambient and room air conditions. To obtain a more accurate estimation, information pertaining to these parameters is needed.

LBNL conducted an initial search of studies on PACs to identify available data and reports. We could not identify past research that reported actual energy use of PACs in the field. Thus, we designed our field study to obtain data on the required variables, i.e. capacity, hours and modes of operation, and power consumption, along with ambient air conditions and users’ temperature settings, to more accurately estimate AEU. The input parameters used in the calculation of AEU are discussed in detail below.

3.1.1 Capacity

PACs are sold by capacity measurement (Btu/hr) which is noted on the manufacturer’s unit label. The appropriate capacity for a PAC depends primarily on the square footage of the space to be cooled.

Figure 3-1 shows recommendations, taken from an online search, for PAC capacity based on the square footage of the space which the unit is intended to cool.

BTU Calculator for Portable Air Conditioners

Room Size in Feet	Area Sq. Ft.	Recommended BTU's	Full Sun	Kitchen
20 x 30	600	14,000	15,400	18,000
20 x 20	400	12,000	13,200	16,000
15 x 20	300	10,000	11,000	14,000
10 x 20	200	8,000	8,000	12,000

Figure 3-1 Recommended Cooling Capacities[3]

3.1.2 Hours and Modes of Operation

Hours of operation are important variables for calculating the energy use of a PAC. The measurement must distinguish hours of operation by mode of operation (cooling, fan-only, or off/standby). Each mode consumes a different amount of energy.

3.1.3 Energy Efficiency

The energy efficiency of a PAC, which is calculated under specified test conditions, is defined as its capacity for cooling ambient air per unit of energy consumed. It is a measure of the amount of power necessary to achieve a desired temperature level in an enclosed space of a given size. This efficiency indicator is usually provided by the manufacturers along with capacity information. This indicator of PAC energy efficiency is reported in terms of the energy efficiency ratio (EER), which is the cooling capacity divided by the electrical power input.

3.2 Sources of Data Used in Analysis

Few sources of data that could serve as inputs to calculating the AEU of PACs were available. No field studies were found. Only one publically available database regarding PAC ownership, operation, or energy consumption was found. National-based surveys, such as the Residential Energy Consumption Survey and the Commercial Building Energy Consumption Survey performed by DOE's Energy Information Administration, collect information on the use of room ACs, but not on the use of PACs. The California Energy Commission (CEC), however, maintains data on PACs, which is helpful for estimating energy use. Additionally, some of LBNL's past research efforts have produced information helpful to our study. We discuss below the relevant data from the CEC and LBNL past research efforts.

[3] Source: The Home Depot:Conditioners. http://www.homedepot.com/c/air_conditioners_HT_BG_AP. Last accessed December 8, 2014.

3.2.1 California Appliance Database

The California Energy Commission (CEC) collects data on many household appliances, including PACs (which the CEC terms "spot air conditioners" and places within the category of "non-central AC and HP products").[4] The CEC database provides information on almost 350 PAC models from more than 20 manufacturers. It should be noted that some of these units are ductless. The database lists the manufacturers Denso, GD Midea, and Gree multiple times under slightly different names**.** Table 3-1 shows the number of PAC models by manufacturer.

Table 3-1 CEC Database: Manufacturers and Numbers of Models*

Manufacturer	No. of Models
Compu-Aire	5
DeLonghi America, Inc.	35
Denso Products and Services Americas, Inc.	14
Denso Sales California, Inc.	14
Diversity Industries, Inc.	32
Egang Co., Ltd	3
Friedrich	3
GD Midea Air Conditioning Equipment Co., Ltd.†	28
GD Midea Commercial Air-Conditioning Equipment Co.†	15
Gree Air Conditioning	2
Gree Electric Appliances, Inc. of Zhuhai	31
Haier America Trading, LLC	98
Kaiping New Widetech Electric Co., Ltd. Kelon Air Conditioner Co., Ltd.	4
Koldwave Division, Mestek, Inc.	4
LG Electronics, Inc.	8
Midea Refrigeration & Air Conditioning	1
Mobil Air, Inc.	1
Ningbo Bole Electric Appliance Co., Ltd.	2
Sharp Electronics	20

[4] California Energy Commission. http://www.appliances.energy.ca.gov/QuickSearch1024.aspx.http://www.energy.ca.gov/appliances/. Last accessed December 7, 2014.

Manufacturer	No. of Models
Virco Associates, Inc.	1
YOAU Electric	18
Zhejiang Aoli Electric Appliance Co., Ltd.	1

* Database last viewed August 25, 2014.

† Manufacturers of the Frigidaire brand.

Figure 3-2 shows the distribution of PAC models by cooling capacity as reported in the CEC database. The data indicate that a majority of models (approximately 84 percent of the models in the database) have a cooling capacity between 7,000 and 14,999 Btu/hr. Thirteen percent of PAC models in the database report a cooling capacity greater than 19,000 Btu/hr. Those higher-capacity models likely are used in heavier commercial applications, not in residential or light commercial settings.

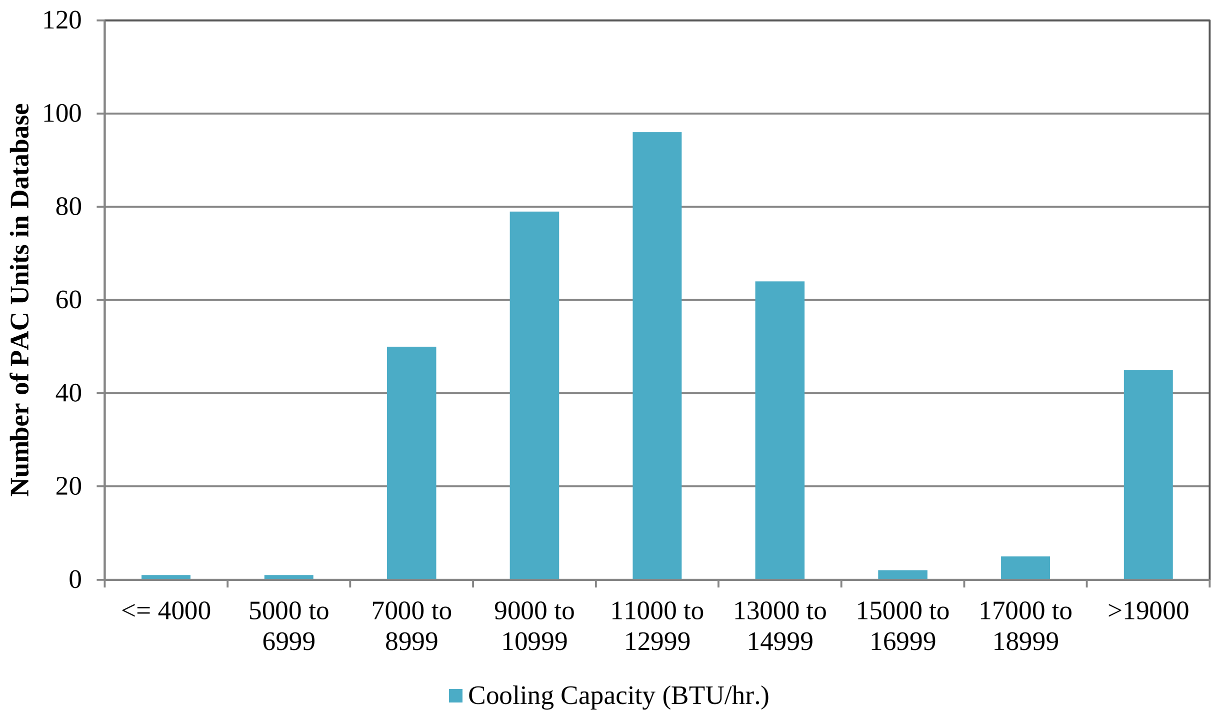


Figure 3-2 CEC Database: Number of Models by Cooling Capacity

The parameters listed in the CEC database for PACs are: manufacturer name, brand name, model number, capacity (Btu/hr), cooling efficiency ratio (CER), and the date for which the record was added to the database. The CEC calculates a unit's CER, which is an efficiency metric equivalent to EER, by "dividing the sum of the cooling capacity and the fan electrical input (both in Btu/hr), by the total electrical input in watts."[5] The higher the CER, the more efficient the PAC is. Table 3-2 shows the number of PAC models having a given CER by cooling capacity.

Table 3-2 CEC Database: Cooling Efficiency Ratios for Various Capacities*

Cooling Capacity (Btu/hr)	Cooling Efficiency Ratio (CER)								Total No. of Models
	7 to 7.99	8 to 8.99	9 to 9.99	10 to 10.99	11 to 11.99	12 to 12.99	13 to 13.99	>14	
	No. of Models								
<= 4,000				1					1
5,000 to 6,999		1							1
7,000 to 8,999	14	11	9	15		1			50
9,000 to 10,999		17	52	9		1			79
11,000 to 12,999		19	51	25	1				96
13,000 to 14,999		6	21	22	13	1		1	64
15,000 to 16,999			2						2
17,000 to 18,999			2			2	1		5
>19,000		6	9	13	4	2	6	5	45

***Database last viewed August 25, 2014.

3.2.2 Manufacturers- reported Information

LBNL reviewed data on 224 PAC models from many large online retailers to gain a better understanding of the models' average EER based on their cooling capacity measured in Btu/hr. The data were taken directly from manufacturers' reported values for cooling capacity and EER. Typical models had EER values of 9.5 Btu/Wh, with a range of 8.2 to 14.3 Btu/Wh. Table 3-3 shows the average EER reported by manufacturers for single- and dual-duct PAC models based on the cooling capacity. It is important to note that these data are likely derived from different test conditions than the CEC data. CEC requires the use of an obsolete version of ASHRAE 128 (from 2001), that has different test temperatures than any of the current test methods (ASHRAE 128, AHAM PAC-1, CSA C370). Also, since there are no standards or labeling requirements, manufacturers can test at any conditions they choose for these self-reported values.

[5] California Energy Commission. *Appliance Efficiency Regulations*. CEC 400-2005-012. April 2005. http://www.energy.ca.gov/2005publications/CEC-400-2005-012/CEC-400-2005-012.PDF. Last accessed December 8, 2014.

Table 3-3 EERs of PACs by Duct Type and Capacity

Single-Duct PAC		Dual-Duct PAC	
Cooling Capacity (Btu/hr)	**Average EER**	**Cooling Capacity (Btu/hr)**	**Average EER**
5,000	8.50		
7,000	8.73	7,000	10.80
8,000	8.62	8,000	8.90
8,100	8.90	9,000	9.27
9,000	9.43	9,300	9.40
10,000	9.89	10,000	8.89
10,500	9.50	11,000	9.19
11,000	8.90	11,600	8.80
11,500	9.00	12,000	10.61
12,000	9.97	13,000	9.21
13,000	11.09	13,500	9.50
14,000	9.95	14,000	10.33

4 SELECTION AND CHARACTERISTICS OF STUDY SITES

LBNL conducted a PAC field-metering study in the Northeastern United States in the summer of 2014. For the study, LBNL targeted the areas around Syracuse, New York, and Philadelphia, Pennsylvania, because those areas typically experience high summer temperatures, have no central AC, and thus could show relatively high PAC use. LBNL's goals were to expand the understanding of (1) energy use and operational modes of PACs; and (2) the effect of room square footage on the cooling capacity of PACs. We considered a climate-controlled space to have a finished ceiling, floor, and walls and is either heated or cooled. Table 4-1 summarizes the metering installations for this field study.

Table 4-1 Summary of Study Plan

Factor	Syracuse, NY	Philadelphia, PA
Number of PAC units monitored	4	15
Date of first installation	July 21, 2014	July 17, 2014
Date of last installation	July 27, 2014	August 13, 2014
Date to begin retrieving meters	October 15, 2014	October 15, 2014

4.1 Site Selection

LBNL's site selection process focused on recruiting, screening, and selecting sites that would provide energy use data from PACs used in a range of both residential and light commercial settings. Obtaining representative energy use data allows us to characterize the variability of

PAC in operation, which may also give indication of PAC usage in larger PAC ownership market.

We first recruited potential participants in both the Philadelphia and Syracuse areas through personal contacts. Additionally, in the Philadelphia area, we emailed a flyer describing the study to individuals, organizations, and list services. This effort yielded an estimated outreach to approximately 800 to 1,000 individuals. The combined methods generated 3 likely sites in the Syracuse area and 16 likely sites in the Philadelphia area. The initial recruitment round had a goal of 9 Philadelphia sites. LBNL later adjusted its Philadelphia site recruitment to 14 sites. Because some initial Philadelphia sites were eliminated from the study based on screening criteria (see Section 4.2), or occupants chose to drop out, we repeated the recruitment methods to obtain additional participants in the Philadelphia area. The recruitment effort resulted in 3 final sites in the Syracuse area and 16 in the Philadelphia area. The 19 measurement sites were on 14 different properties (5 Philadelphia sites were office spaces including unoccupied server rooms located within in a theological seminary, and 2 other sites were located in the same single-family home).

4.2 Site Visits and Screening Criteria

LBNL conducted a preliminary visit to each potential site in order to obtain occupants' consent for the study as required by the LBNL IRB, and to collect general household information. During this visit, LBNL interviewed occupants using a survey of about 40 questions on PAC characteristics and usage habits and 13 questions regarding household and demographic characteristics. The following information were collected.

- square footage of PAC site and residence;
- general description of PAC site and residence;
- number of occupants and their ages;
- occupants' schedules;
- frequency of PAC use;
- characteristics of PAC unit (brand, capacity, etc.); and
- method used to control the unit (e.g., anticipated set points, control settings, whether manual or automatic control, and method of condensate removal).

The visits also allowed us to take photographs of the site, and the PAC location and configuration, brainstorm potential locations for sensors and other metering equipment, and finalize monitoring plans. The criteria most important to final site selection were (1) estimated amount of PAC use; (2) general conditions (confirming that the PAC unit was functioning properly and there were no issues with the test environment); and (3) distance to travel to the site. Several sites were excluded, including one located in a lobby where adjoining rooms had window air conditioners. One test site was rejected because of the long travel time to the site.

Some of the sites that were admitted to the study during the second round, such as households that were intermittent PAC users, were subjected to less stringent criteria than applied to the initial selection of sites.

4.3 Site Characteristics

In this report, the study sites are identified as Site 01 through Site 19. Table 4-2 and Table 4-3 provide information on the 19 sites, including characteristics of residences, conditioned spaces, and PACs; PAC models and ducting configurations; date monitoring equipment was installed; and PAC settings. Temperature settings for heating and cooling are as reported by homeowners. PAC control settings also are based on homeowner reports, confirmed, when feasible, by observation during installation of monitoring equipment.

Table 4-2 Characteristics of Test Sites and PAC Settings

Site ID	State	Sector	Room Area (sq. ft.)	Building Area (sq. ft)	Date Equip. Installed	Typical Set Point (°F)	Typical Fan Setting	Use for Dehumidification
Site 01	NY	Commercial	285	3,000	7/21/2014	72	High	No
Site 02	NY	Residential	1,500	1,500+b*	7/25/2014	72-76	High	No
Site 03	NY	Residential	144	2,400+b*	7/27/2014	77	3 of 4	No
Site 04	PA	Commercial	277.5	21,000	7/29/2014	75	Low	No
Site 05	PA	Commercial	390	21,000	7/30/2014	72	Low	No
Site 06	PA	Commercial	48	21,000	7/30/2014	75	Low	No
Site 07	PA	Commercial	161.5	17,000	7/31/2014	72	Low	No
Site 08	PA	Residential	127.4	2,500	7/30/2014	75	Low	No
Site 09	PA	Residential	241.5	8,000	7/30/2014	75	Med	No
Site 10	PA	Commercial	100	17,000	7/31/2014	72	Low	No
Site 11	PA	Residential	141	1,820	7/31/2014	73	Low	No
Site 12	PA	Residential	238	1,800	8/4/2014	68	Low	No
Site 13	PA	Residential	864	3,200	8/4/2014	75	High	No
Site 14	PA	Residential	175	2,500	8/4/2104	73	Low	No
Site 15	PA	Residential	81	3,000	8/14/2014	66	High	No
Site 16	PA	Residential	208	600+b	8/9/2014	75	High	No
Site 17	PA	Residential	203	2,500	8/13/2014	75	Low	No
Site 18	PA	Residential	280	3,400	8/13/2014	75	Low	No
Site 19	PA	Residential	280	2,400	8/13/2014	74	Low	No

*b indicates the residence has a basement that is not included in the building area estimation.

Table 4-3 Specifics of Metered PACs

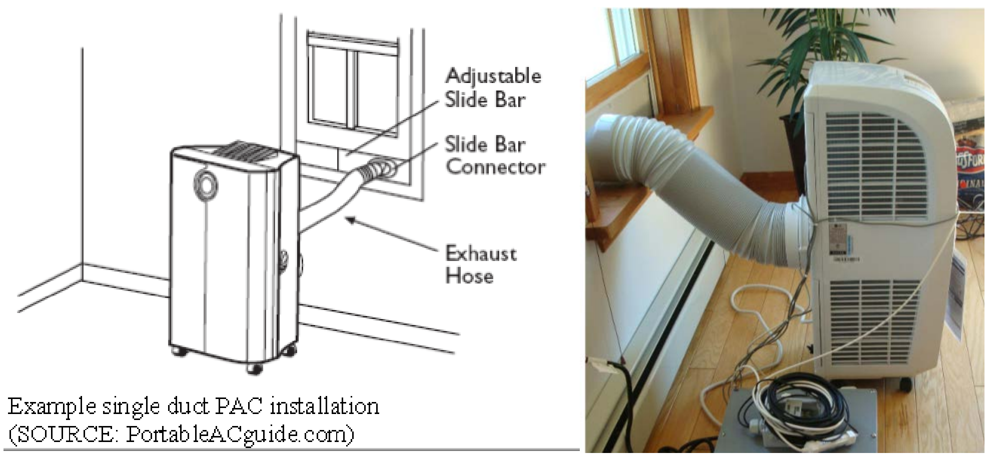
Site ID	Make	Model	PAC Capacity (Btu/hr)	PAC Power (watts)[6]	Manufacturer-reported EER	Duct Type	Presence of condensate bucket	Outlet for Duct	Duct Length (ft.)	Duct Area (sq. ft.)[7]
Site 01	LG	LP0814WNR	8000	880	9.1	Single	No	Double-hung	3	0.165
Site 02	Everstar	MPA-08CR	8000	970	8.2	Single	Yes	Awning	8	0.11
Site 03	Soleus Air	GL-PAC-08E4	8000	760	10.5	Single	No	Awning	12	0.136
Site 04	Tripp Lite	SR Cool 12K	12000	1400	8.6	Single	No	Acrylic panel	2	0.15
Site 05	LG	LP1311BXR	13000	1340	9.7	Single	No	Casement	4.5	0.11
Site 06	Tripp Lite	SR Cool 12K	12000	1400	8.6	Single	No	Exhausted to attic	6	0.087
Site 07	LG	LP1311BXR	13000	1340	9.7	Single	No	Exhausted through ceiling	7	0.165
Site 08	Haier	HPE07XC6	7000	800	8.8	Single	No	Double-hung	3	0.11
Site 09	GE	APE08AKM1	8000	1420	5.6	Single	Yes	Double-hung	6	0.136
Site 10	LG	LP1311BXR	13000	1340	9.7	Single	No	Exhausted through ceiling	7	0.136
Site 11	Commercial Cool	CON10XCJBE	10000	1100	9.1	Single	No	Casement	4	0.136
Site 12	LG	LP1213GXR	12000	1270	9.4	Single	No	Double-hung	6	0.136
Site 13	SPT	WA-114ODE	11000	1253	8.8	Dual	No	Glass block	6	0.136
Site 14	Soleus Air	SG-PAC-O8E4	8000	760	10.5	Single	No	Double-hung	4	0.134
Site 15	Everstar	MPN1-11CR-BB4	11000	1345	8.2	Single	No	Double-hung	4	0.136
Site 16	LG	LP0814WNR	8000	880	9.1	Single	No	Double-hung	4.5	0.15
Site 17	Edgestar	AP8000W	8000	840	9.5	Single	No	Double-hung	2	0.136
Site 18	Royal Sovereign	ARP 1000ES	10000	2900	3.4	Single	No	Double-hung	3	0.136
Site 19	Soleus Air	PE3-12R-03	12000	1200	10.0	Dual	No	Double-hung	3	0.165

[6] Rated power from name plate
[7] Cross-section of duct

In addition to preliminary site visit information, we also collected detailed information including:

- number of floors in the building, age, type of central heating system, and type of central cooling system (if any);
- utility bills (gas, electric, other) if available;
- sketch showing the location of the PAC in the home (room number and size, floor area, location from exterior, wall(s), window types and areas, orientation, heat sources in the space);
- PAC model number, rated capacity, ducting type, nameplate details; and
- PAC configuration (location in room, duct lengths, control settings on unit).

The study included only 2 dual-duct units, along with 17 single-duct units. Figure 4-1 illustrates the installation of a single-duct PAC, including a photo of the installation at Site 01. Figure 4-2 demonstrates two different methods for installing dual-duct PACs, as well as an image of the installation at Site 19.



Example single duct PAC installation
(SOURCE: PortableACguide.com)

Figure 4-1 Sample Installation of Single-Duct PAC

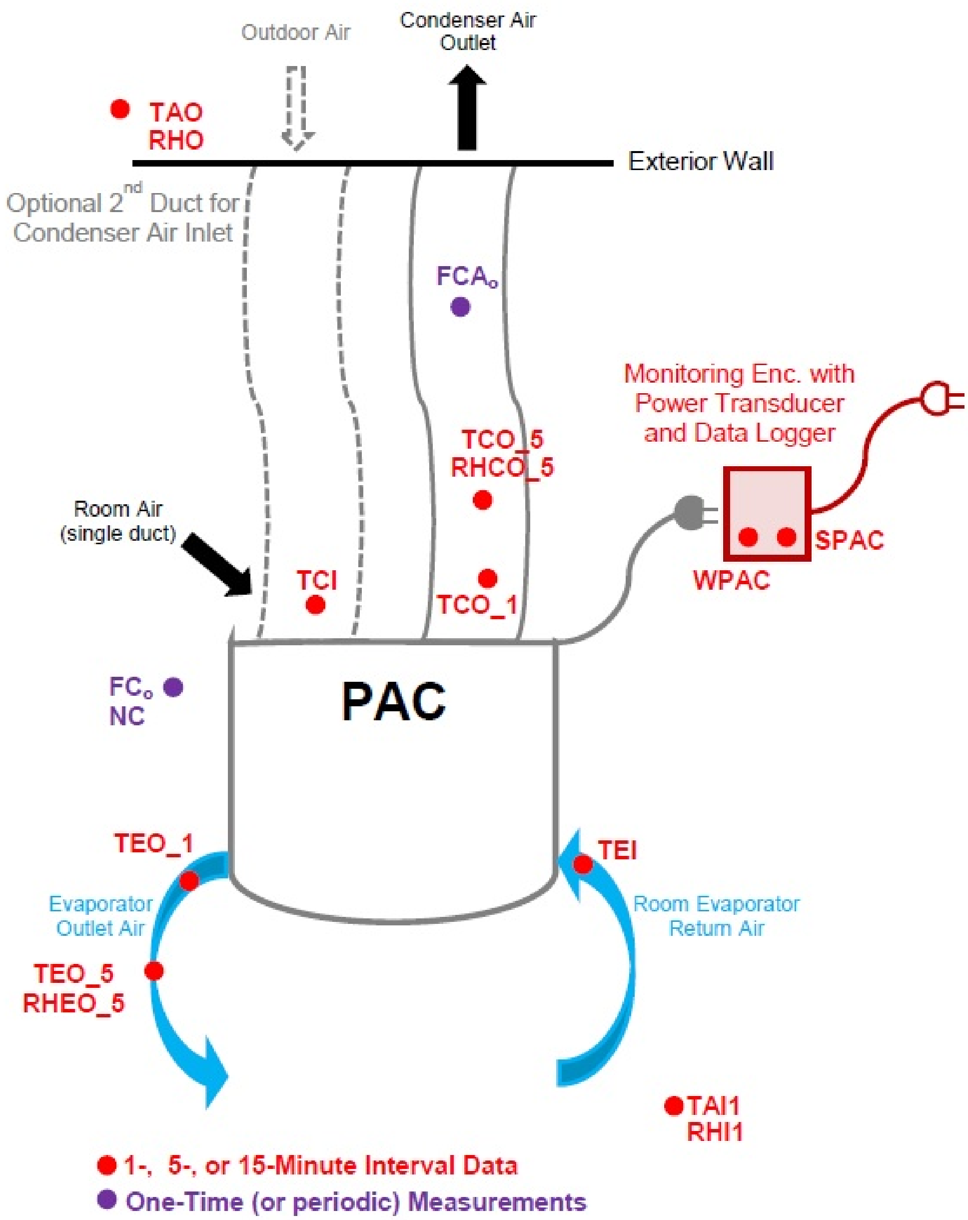
Figure 4-2 Sample Installation of Dual-Duct PAC

5 DATA COLLECTION

The 19 study sites were metered from July 2014 to mid-October 2014. After surveying participants regarding the particulars of their site and building, LBNL collected data on the energy consumption of the PACs by placing energy-metering devices and temperature/relative humidity (T/RH) sensors at the sites. This section describes LBNL's monitoring approach and rationale for each PAC measurement and describes the sensors and equipment used in the study.

5.1 Monitoring Approach

Figure 5.1 shows the overall layout of the PAC metering systems and the locations of monitoring points. The power consumption (**WPAC**) and runtime (**SPAC**) of the PAC unit were measured to determine runtime hours and energy use. We measured the temperature and humidity conditions in the space where the unit was located to confirm the level of comfort that was being provided (**TAI1, RHI1**). We also measured the temperature right at the unit evaporator inlet (**TEI**). The supply conditions from the unit (**TEO, RHEO**) were used to confirm whether the unit operated as expected. The condenser outlet conditions (**TCO, RHCO**) were measured inside the duct. Depending on the type of unit, the condenser inlet temperature (**TAI1** for a single duct; **TCI** for a dual duct) would indicate the temperature difference across the condenser. The outdoor conditions (**TAO, RHO**) and optional space conditions in other areas **(TAIn, RHIn**) completed the data set collected for this study. Condensate flow from the PAC unit was determined by a volume measurement (**FC**) of the PAC's condensate reservoir holding capacity (i.e., at the level when the switch turns the unit off). Condenser air flow (**FCA**) was also measured. We asked homeowners, whose units had reservoirs, to log each date and time they emptied the reservoir (**NC**). Local weather station temperature **(TWUG)** was matched with the metered data set.



5.1 Schematic Showing Location of Data Points (dotted lines show optional dual duct)

5.2 Monitoring Instrumentation and Measurement Intervals

LBNL used battery-powered Onset HOBO loggers to collect time-synchronized data at 1-minute, 5-minute, and 15-minute intervals. Data from those low-cost, battery-powered loggers were collected manually twice: (1) in the middle of the monitoring period (mid-summer), and (2) after the cooling season had ended. The mid-point data collection enabled us to confirm proper operation of the systems as well as to collect one-time (or periodic) readings under actual summer conditions. HOBO loggers are described further in section 5.2.1; other data loggers are described in section 5.2.2. The above readings confirmed that the PAC units were installed appropriately and that both the units and data sensors were functioning normally.

During each of three site visits (initial, mid-point visit, and equipment removal), we used handheld instruments to take the following readings: (1) TSI probe was used to confirm temperature and RH readings; (2) TSI VelociCalc probe was used to measure air velocity at three to five points across a straight section of the outgoing air duct in order to calculate condenser airflow; (3) Fluke meter was used to confirm power measurements collected with the Wattnode pulse meter and to take one-time readings of evaporator and condenser fan power (when possible), as well as power readings for the entire unit in its various operating modes.

The above readings confirmed that the PAC units were installed properly and that both the units and the data sensors were functioning normally. Table 5-1 lists the equipment used to monitor and log the parameters measured during each of the three site visits, as well as equipment used only during the initial site visit.

Where possible, the HOBO loggers were configured to collect data at 1-minute intervals. The newer, higher-capacity UX120 series HOBOs can hold at least several months' worth of data collected at 1-minute intervals (the UX120-17M stores 4 million readings; the UX120-06M stores 1.9 million). The lower-capacity HOBO loggers (the UX100-023 used for recording T/RH) can store 84,000 readings, or about 2 to 4 months' worth of data collected at 5-minute intervals. The U12-011 and U23-002 loggers hold 43,000 readings, which can accommodate about 3 to 4 months' worth of data collected at 15-minute intervals. The data-holding capacity of the lowest-capacity HOBO dictated the interval between site visits.

The HOBO logger used to collect the temperature and humidity of the PAC space was set on top of a piece of furniture or hung on a wall, depending on the homeowner's preference. The outdoor temperature sensor was mounted in an appropriate shaded location.

The Wattnode power transducer and data loggers were placed inside a plastic electrical enclosure measuring 12 by 12 by 6 inches. The enclosure, plugged into a wall, had a grounded outlet into which the PAC unit could plug. The pulse-counting logger (UX120-017M) was installed next to the Wattnode power transducer. The Wattnode voltage tap was fused. The data logger having external temperature probes (UX120-06M) also was placed inside the electrical enclosure. The enclosure sat on the floor next to the PAC. The 6-foot external temperature probe(s) extended out from the enclosure to the flex duct(s) as well as to the front of the PAC unit to measure unit supply temperature.

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Table 5-1 Parameters Studied and Equipment Used

Parameter	Sensor	Data Logger
All Site Visits (installation, mid-point, and removal)		
WPAC	Wattnode WNB-3Y-208-P	HOBO UX120-017M
SPAC	Verts H300	20 amp CT (0.5 Wh/pulse)
TAI1	HOBO U12-011 (ambient air)	
RHI1		
TEO_1	TMC6-HD	HOBO UX120-006M
TEI	TMC6-HD	
TCO_1	TMC6-HD	
TCI	TMC6-HD	
TEO_5 RHEO_5	HOBO UX100-023 (remote probe)	
TCO_5 RHCO_5	HOBO UX100-023 (remote probe)	
TAO RHO	HOBO U23-002 (remote probe)	
TAIn	HOBO U12-011 (space)	
RHIn		
TWUG	*Weather Underground*: http://www.wunderground.com/	
Initial Site Visit Only		
FCA	TSI 9545 VelotiCalc	
FC	Reservoir volume check	
Logged by Homeowner		
NC	Number of times reservoir was emptied	

Table 5-2 lists the data points monitored during the field study and measurement parameters and their logging intervals. The measurements were confirmed using one-time measurement devices during a maximum of three site visits (initial installation, mid-point, and equipment removal). In some cases unit outlet temperatures (TEO_1, TCO_1) were measured at 1-minute intervals while also being collected, along with humidity, at 5-minute intervals at the condenser and evaporator (TEO_5, RHEO_5; TCO_5, RHCO_5). The 1-minute data indicate the unit dynamics; the 5-minute T/RH data enable determination of the psychrometric properties of the ambient air.

Table 5-2 Measurement Intervals

Parameter	Description of Data	Collection Interval	Units
All Site Visits (installation, mid-point, and removal)			
WPAC	PAC power	1 minute	W
SPAC	PAC runtime	1 minute	minutes
TAI1	Temperature of air entering PAC	15 minutes	°F
RHI1	Relative humidity of air entering PAC	15 minutes	% RH
TEO_1	Evaporator outlet temperature	1 minute	°F
TEI	Evaporator inlet temperature	1 minute	°F
TCO_1	Condenser outlet temperature	1 minute	°F
TCI	Condenser inlet temperature	1 minute	°F
TEO_5	Evaporator outlet temperature	5 minutes	°F
RHEO_5	Evaporator outlet humidity	5 minutes	% RH
TCO_5	Condenser outlet temperature	5 minutes	°F
RHCO_5	Condenser outlet humidity	5 minutes	% RH
TAO	Outdoor ambient temperature	15 minutes	°F
RHO	Outdoor relative humidity	15 minutes	% RH
TWUG	Local weather station temperature	60 minutes	°F
TAIn	Additional room *n* space temperature	15 minutes	°F
RHIn	Additional room *n* relative humidity	1 minute	% RH
Initial Site Visit Only			
FCA	Condenser air flow	Once	cfm*
FC	Condensate reservoir capacity	Once	gal
Logged by Homeowner			
NC	Number of times reservoir was emptied	Multiple	#

* cfm = cubic feet per minute.

6 DATA ANALYSIS

This section describes how LBNL processed the data after it was collected and then how LBNL analyzed the data after it was processed.

6.1 Preliminary Analysis and Database Development

Data from all meters were collected in a comma-separated value (csv) format. The raw data for each site came in separate csv files based on the timestamp interval. All the csv files were merged based on timestamps. To simplify data analysis, gaps in the timestamps related to the different collection intervals were linearly interpolated. Only those timestamps from the 1-

minute interval raw data were retained (e.g., if there were more outdoor weather data than 1-minute data, the excess outdoor data were dropped). When a complete 1-minute, gapless dataset was derived for each site, that dataset, along with the site ID, was incorporated into a single data table. The merged, interpolated, and combined data table was input to a Microsoft Access database. The database contained a total of 1,899,753 records for the 19 sites.

6.2 Analytical Methods

We used Microsoft Excel to connect with and perform analyses on the Access database. Pivot reports were used to calculate averages, standard deviations, and average trends based on the records. Time series were examined for individual sites to examine data trends throughout the metering period.

6.3 Definitions of Operational Modes

Based on the field-metered data, each PAC operated in one of three modes: cooling mode, fan mode, or off/standby mode. Each 1-minute record was assigned to one of the modes based on the power consumption during that minute. The power limits that define each mode are listed in Table 6-1.

Table 6-1 Operational Mode as Defined by Power Use

Mode	Power Use
Off/Standby	≤ 30 W
Fan	>30 W and ≤ 270 W
Cooling	>270 W

7 ANALYTICAL RESULTS AND DISCUSSION

This section discusses the results of our analysis of the PAC field data. Typical time-series plots are given for PACs in both residential and light commercial settings. We also calculate the amount of time PACs spent in each operational mode in both residential and light commercial settings. We demonstrate the effect of time of day on PAC operation. We summarize the average PAC power consumption for each operational mode at each site. We show the correlations between average PAC power consumption and thermal conditions of the room and outdoor area. We determine the actual PAC capacity and in-field efficiency. Finally, we derive an outdoor temperature-dependent annual energy use model for residential and light commercial settings.

7.1 PAC operational patterns

The following sections present typical time-series plots for both residential and light commercial sites. The figures below show the time series for the full metering period (top), a 4-day view (middle), and a 12-hour view (bottom). PAC power consumption (watts) is plotted along with the room temperature and outdoor temperature.

7.1.1 Example of PAC usage in residential setting

Figure 7-1 presents a time-series from typical usage of a PAC unit in a home (Site 18). The patterns show repetitive daily ambient temperature variations with peak temperature reaching 90 °F for number of days between late-August and mid-September, where the PAC system was in operation. This particular site used the PAC infrequently (4.96 percent in cooling mode, 1.19 percent in fan mode, and 93.13 percent in off/standby mode during the metering period). The operation of the PAC at this test site did not significantly influence the thermal condition of the space, possibly because of its relatively minimal use. This example shows that the user was manually operating the PAC unit as needed.

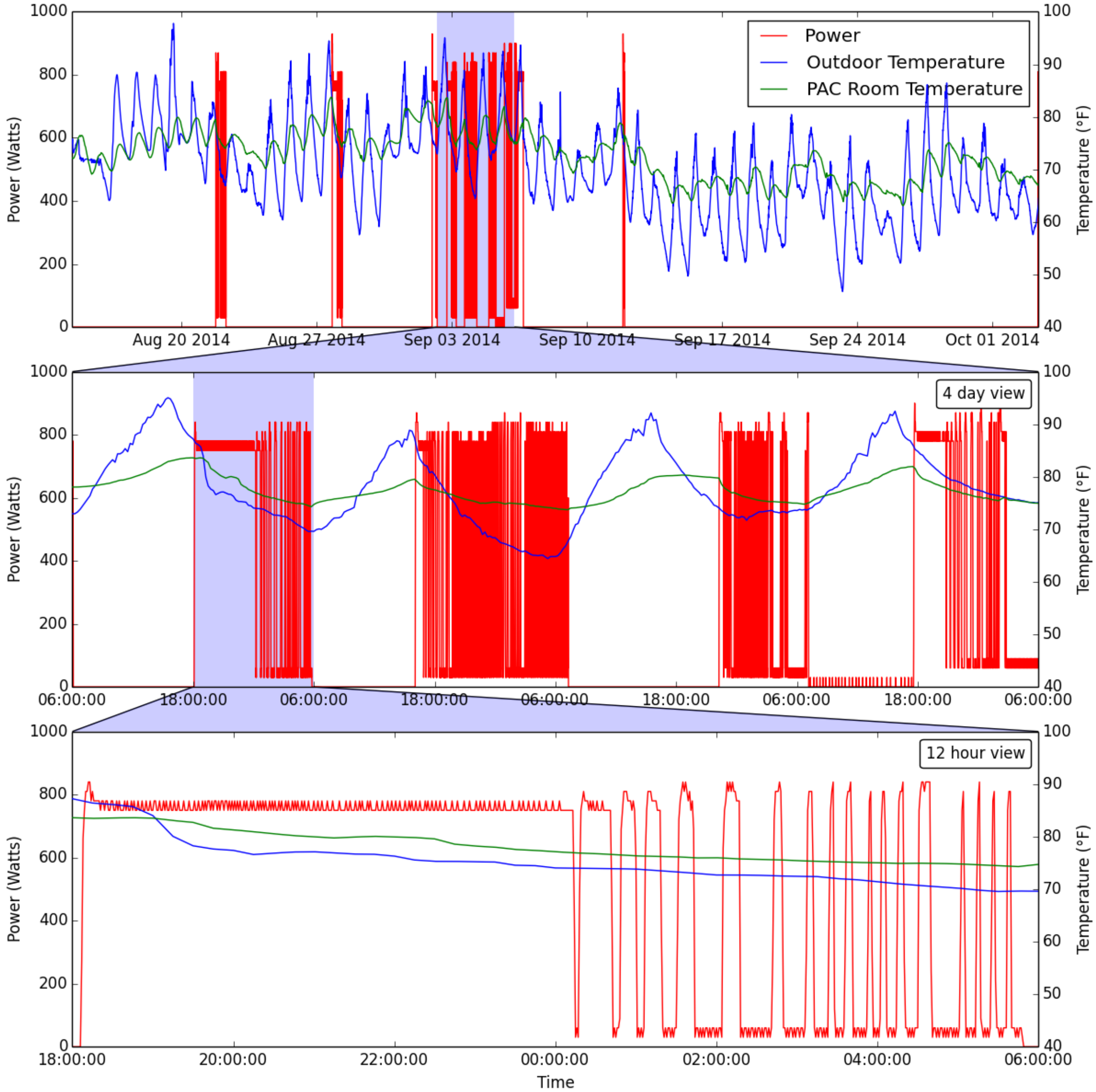

Figure 7-1 Typical Time Series for Residential Site (Site 18)

Figure 7-2 shows a typical residential time series plot with a PAC response to room temperature. During the operation of the PAC, the cooling mode for this site appears to activate at about 83°F and return to off/standby mode at about 72°F.

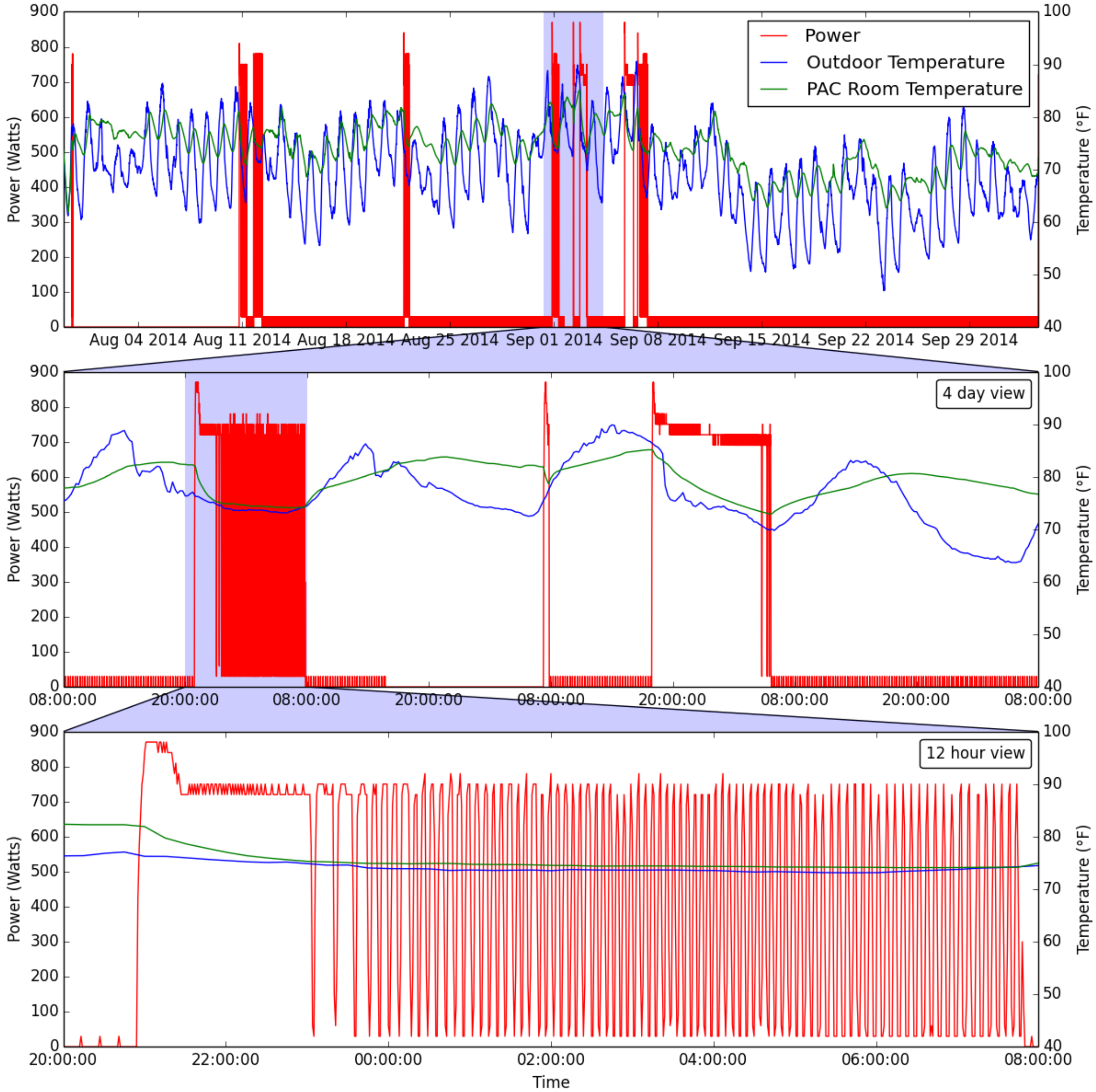

Figure 7-2 Typical Time Series for Residential Site Demonstrating Temperature Response (Site 08)

7.1.2 Example of PAC usage in commercial setting

Figure 7-3 shows the typical usage pattern of a PAC in a light commercial setting. The system was almost continuously running during the period of study. The system operated independent of the outdoor temperature conditions. Throughout the study period, the unit was able to maintain a 72-78°F room temperature, even after mid-September when outdoor temperatures dropped below 70°F. The unit at this site spent 58.3 percent of the metered time in cooling mode, 41.2 percent of the time in fan mode, and 0.6 percent of the time in off/standby mode. The 12-hour view illustrates 31 short cycles moving between cooling and fan mode, or about 2.5 cycles per hour.

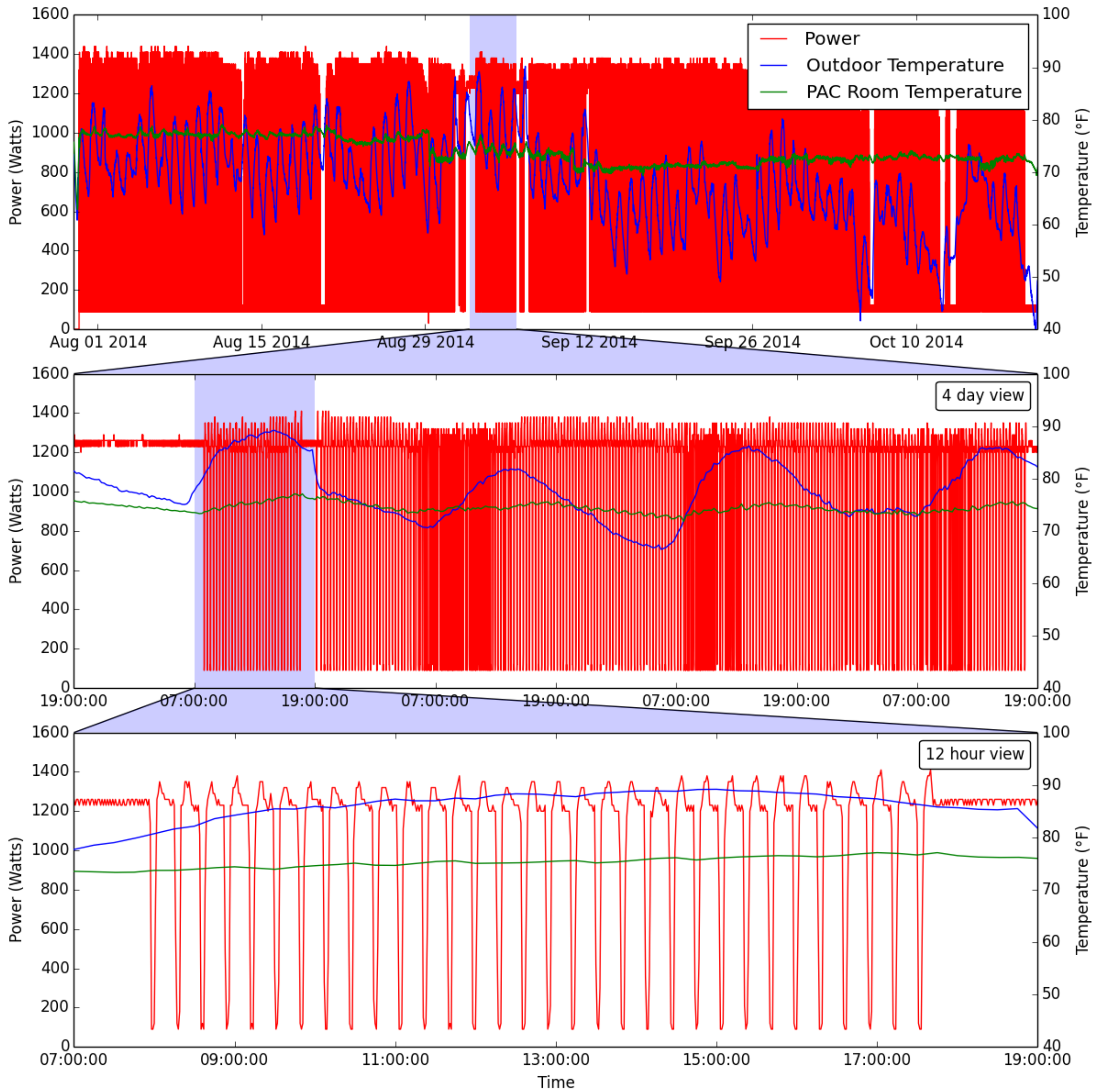

Figure 7-3 Light Commercial Setting: PAC Use (Site 06)

Figure 7-4 shows a PAC in a light commercial setting showing a room temperature relationship. In the four-day view the PAC switches into off/standby mode for about four hours. During this period, the room temperature rises from about 72°F to about 77°F. This particular PAC could not meet the cooling load in August due to relatively high outdoor temperatures and only begins to be able to meet the cooling demand in September and October due to lower outdoor temperatures when the unit switches into off/standby mode for extended periods of time.

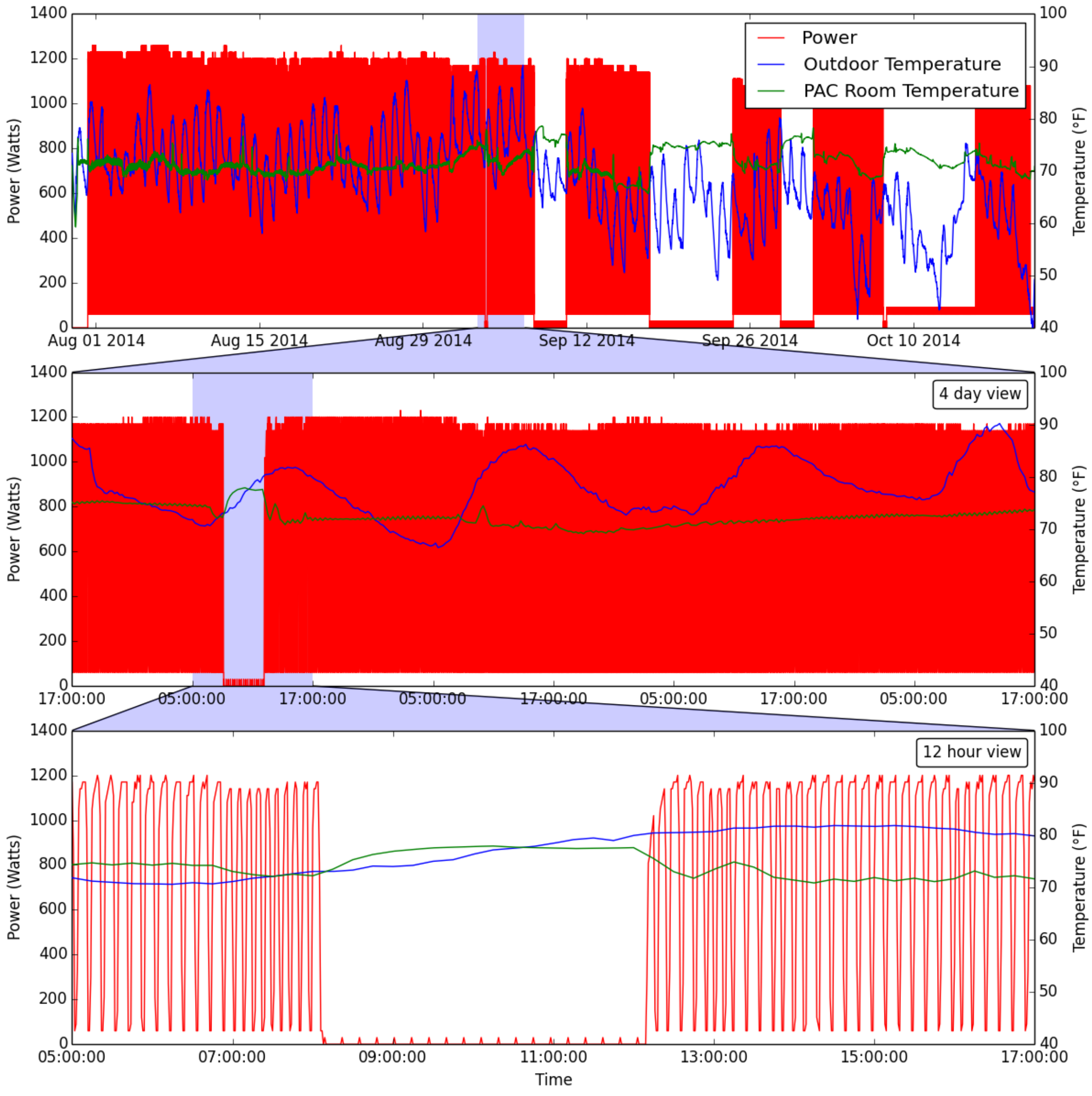

Figure 7-4 Light Commercial Setting: Room Temperature Relationship (Site 07)

7.2 PAC operation time in each operational mode

The following sections describe the percent of metered time spent in each of the three operational modes for both residential and light commercial test sites.

7.2.1 PAC operation time in residential setting

Table 7-1 presents the percentages of time each residential PAC spent in each operational mode. Based on data from the 13 metered sites, PACs spent an average of 4.08 percent of the time in cooling mode, 2.60 percent of the time in fan mode, and 93.32 percent of the time in off/standby mode.

Site 13 spent significantly more time in cooling mode (16.76 percent) than did the other residential sites. Site 15 spent the least amount of time in cooling mode—only 0.13 percent of the monitoring period. This large variation among the test sites indicates that the use of PAC is dependent on other factors, such as user-selected set point and control mode.

Table 7-1 Time Spent in Each Operational Mode, Residential Sites (July 21 – Oct. 15)

Site ID	Cooling Mode (%)	Fan Mode (%)	Off/Standby Mode (%)
Site 02	2.85	1.06	96.08
Site 03	1.86	0.51	97.62
Site 08	3.83	0.46	95.71
Site 09	6.29	0.07	93.64
Site 11	2.61	0.85	96.55
Site 12	3.49	0.01	96.50
Site 13	16.79	16.54	66.68
Site 14	3.63	10.02	86.35
Site 15	0.13	0.05	99.82
Site 16	1.90	0.73	97.38
Site 17	0.76	0.71	98.53
Site 18	4.96	1.91	93.13
Site 19	4.79	2.14	93.07
Average of All Sites	**4.08**	**2.60**	**93.32**

7.2.2 PAC operation time in light commercial sites

Table 7-2 shows the percentages of time for each of the 6 metered light commercial sites spent in each operational mode.

Based on the metered data, the average time PACs in light commercial settings spent in cooling mode was 34.75 percent, a much higher percentage than for PACs in residential settings (average of 4.08 percent). The time spent in fan mode for light commercial settings was much higher on average than for residential sites (22.49 percent compared to 2.60 percent). As shown previously in the usage pattern, the PAC unit used in an office setting was operated almost continuously, unlike units in residences where the users would have more control over the time of operation.

Table 7-2 Time Spent in Each Operational Mode, Light Commercial Sites (July 21 – Oct. 15)

Site ID	Cooling Mode (%)	Fan Mode (%)	Off/Standby Mode (%)
Site 01	11.82	5.80	82.39
Site 04	50.46	44.49	5.05
Site 05	3.43	0.04	96.53
Site 06	58.25	41.19	0.56
Site 07	50.20	32.05	17.75
Site 10	38.63	14.30	47.07
Average for All Sites	**34.75**	**22.49**	**42.76**

7.3 PAC Cooling Mode and Outdoor Thermal Condition

The sections below present an analysis of the use of PACs (in cooling mode) as a function of time of day. Furthermore, PAC usage in cooling mode is plotted along with the average outdoor temperature to illustrate the correlation. The total cooling mode operation data for all residential sites were binned into hours of the day. The sum of all bins percentage of total cooling mode time is equal to 100 percent (100 percent represents the total time in cooling mode, for example for the residential sites the total is equivalent to 4.08 percent of the total metered time). Residential and commercial sites were examined independently.

7.3.1 PAC cooling mode and outdoor temperature, Residential Sites

Figure 7-5 illustrates that a PAC is used in cooling mode between 10 AM and 10 PM, when higher outdoor temperatures are likely to occur. There was a time lag of about 1 to 2 hours between rising outdoor temperatures and increased PAC usage for cooling. Despite the relatively small usage, there was a discernible diurnal pattern following the time of day: PAC usage was lowest at around 5-6 am (2 percent) and peaked between 6-10 pm (6 percent). One possible cause of the larger percentage of total compressor time occurring between 6 pm and 10 pm is that the manually operated units were turned on when owners returned home from working.

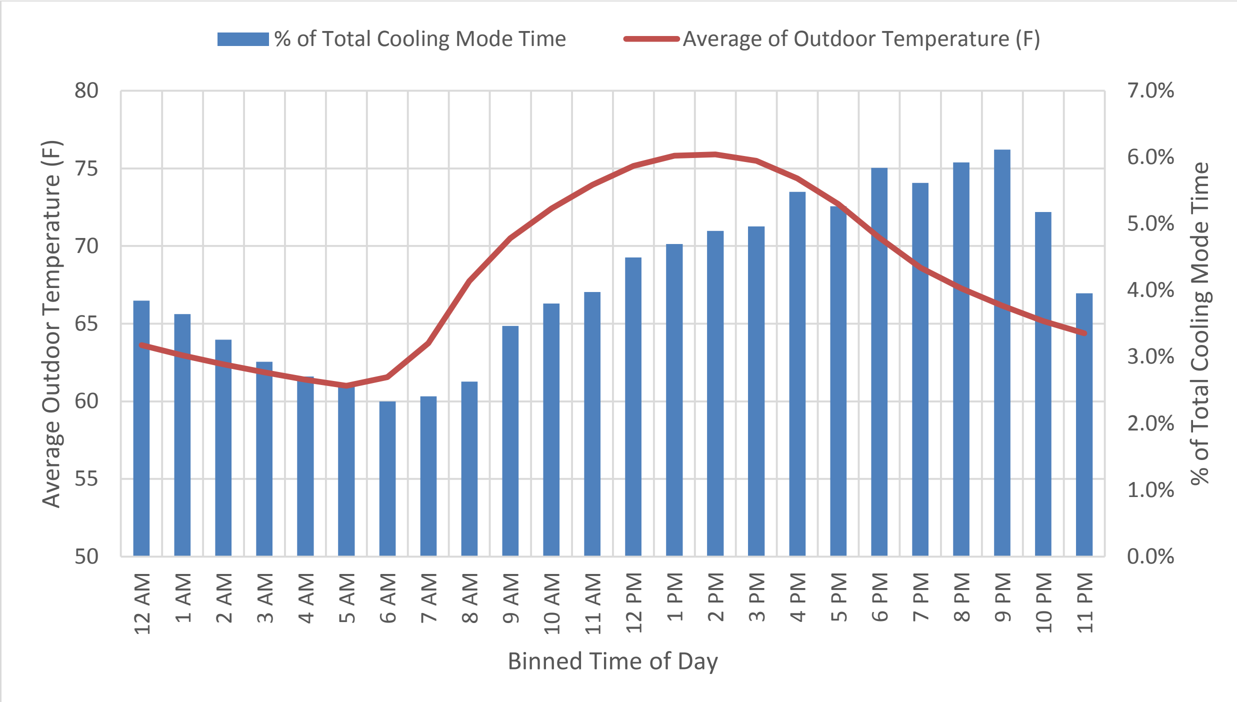

Figure 7-5 Average Percent of Time Spent in Cooling Mode and Average Outdoor Temperature as a Function of Time of Day for Residential Sites

7.3.2 PAC cooling mode and outdoor temperature, Light Commercial Sites

Figure 7-6 shows that PAC cooling use at light commercial sites correlates less with either time of day or outdoor temperature than was observed at the residential sites. The percentage of time under the cooling mode was in the range of 3-5 percent for all the light commercial sites. The peak cooling demand occurred in the late afternoon around 5-6 pm.

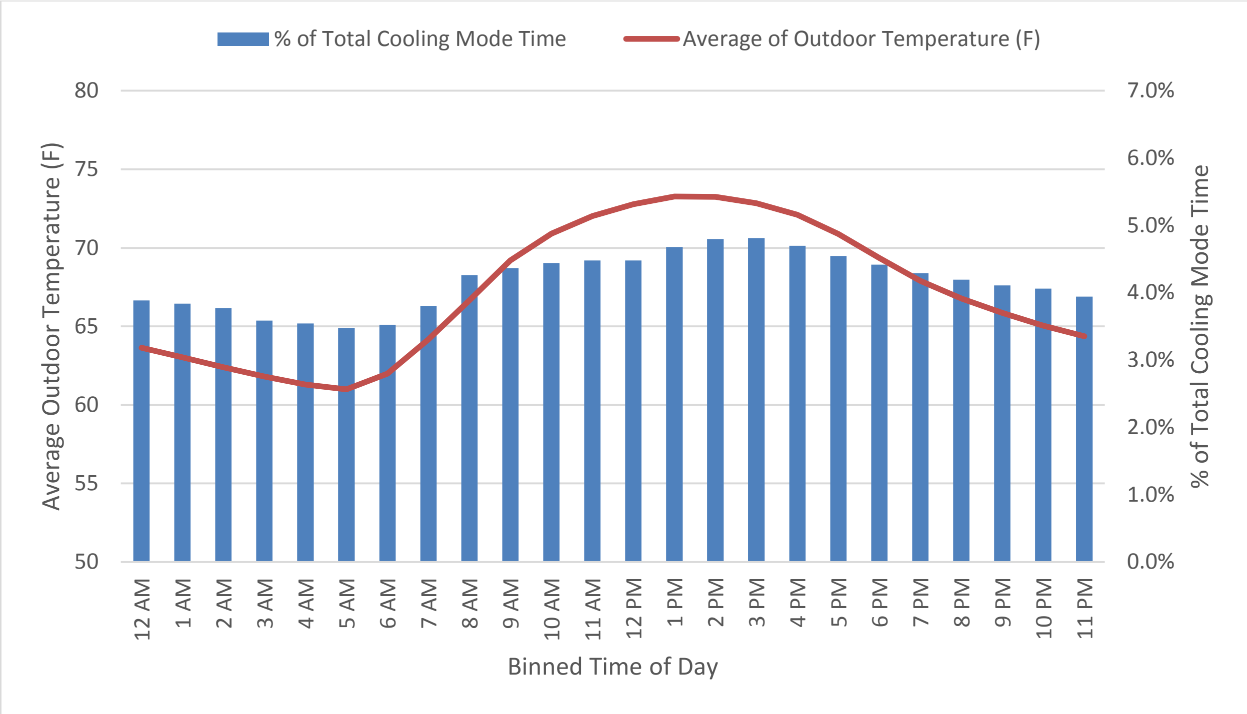

Figure 7-6 Average Percent of Time Spent in Cooling Mode and Average Outdoor Temperature as a Function of Time of Day for Commercial Sites

7.4 Power Used in Each Operational Mode

Table 7-3 lists the average and standard deviation of measured power consumption of the PAC units at all sites for each of the three operational modes. The threshold for off/standby mode is 30W, most of the measured values were closer to zero, but other readings between 0 and 30 W led to a high standard deviation.

Table 7-3 Average and Standard Deviation of Power by Mode for Each Site

Site ID	Average Power (W)			Standard Deviation for Power (W)		
	Cooling Mode	Fan Mode	Off/Standby Mode	Cooling Mode	Fan Mode	Off/Standby Mode
Site 01	740.9	147.5	1.6	120.8	30.8	6.7
Site 02	1,050.7	77.3	1.6	99.3	27.6	6.7
Site 03	658.6	96.8	0.0	41.2	27.0	0.3
Site 04	1,221.3	109.4	0.0	144.0	18.6	0.0
Site 05	1,099.8	92.5	1.9	68.5	43.2	7.4
Site 06	1,109.6	116.1	0.1	299.9	32.1	1.6
Site 07	1,014.4	76.9	2.2	238.8	36.1	7.8
Site 08	697.8	128.0	2.2	95.3	75.6	7.8
Site 09	1,277.2	99.2	1.7	86.3	69.3	6.9
Site 10	1,176.3	65.9	1.6	169.9	22.2	6.8
Site 11	902.2	91.1	0.3	208.6	61.7	3.0
Site 12	1,214.1	150.0	2.0	48.8	84.9	7.5
Site 13	1,275.5	60.1	29.5	57.2	3.1	3.8
Site 14	616.1	88.9	0.0	76.2	23.5	0.4
Site 15	876.5	74.3	1.5	162.2	46.0	6.5
Site 16	752.3	139.1	1.7	108.6	33.0	6.9
Site 17	791.6	112.3	0.0	163.5	29.6	0.2
Site 18	755.5	73.1	0.2	92.0	40.9	2.6
Site 19	1,049.9	209.3	1.8	62.7	13.5	7.2

7.5 Condenser and Evaporator Measurements during PAC Cooling Mode

This section describes the field measurements collected from the PAC condenser and evaporator during cooling mode. Measurements for both the evaporator and condenser include temperature at the inlet and outlet and humidity readings at the outlet.

7.5.1 Condensers

Table 7-4 presents the air measurements taken at the PAC condensers while in cooling mode, when the condensers are transferring the most heat. The average outlet RH for all sites was about 21 percent, ranging from a low of 13 percent to a high of 42 percent. The average outlet temperature of the condensers was about 113 °F. Site 02, Site 07, Site 09, and Site 13 showed comparatively low average outlet humidity while maintaining high outlet temperatures and low inlet temperatures (resulting in larger outlet-inlet temperature differences).

Table 7-4 Average and Standard Deviation for Condenser Inlet and Outlet Measurements

Site ID	Condenser Outlet Relative Humidity (%)		Condenser Outlet Temperature (°F)		Condenser Inlet Temperature (°F)		Condenser Outlet-Inlet Temperature Difference (°F)
	Average	StdDev	Average	StdDev	Average	StdDev	
Site 01	31.3	6.1	92.7	7.6	73.0	1.1	19.8
Site 02	15.6	9.6	133.2	11.1	76.2	1.7	57.0
Site 03	26.9	9.4	110.2	6.0	75.9	2.0	34.3
Site 04	23.2	9.9	109.5	7.3	69.9	2.4	39.6
Site 05	20.0	6.9	113.9	4.9	78.5	2.0	35.4
Site 06	20.9	3.9	106.5	7.2	71.9	2.0	34.6
Site 07	14.6	4.3	122.7	7.2	73.6	2.0	49.1
Site 08	35.6	6.4	98.5	4.9	74.6	2.3	23.8
Site 09	12.9	6.8	127.9	5.6	76.7	2.6	51.2
Site 10	19.8	7.3	114.7	12.0	77.8	9.4	37.0
Site 11	31.7	6.2	103.4	5.8	74.4	1.7	29.0
Site 12	24.0	4.9	118.8	3.3	86.7	1.8	32.1
Site 13	13.9	3.7	141.9	4.4	79.8	4.1	62.1
Site 14	37.5	12.2	96.9	7.8	71.3	2.4	25.6
Site 15	34.8	10.8	94.8	10.4	69.0	2.2	25.8
Site 16	38.4	9.2	101.8	8.6	75.6	2.0	26.2
Site 17	41.6	13.0	108.6	14.3	77.3	1.8	31.3
Site 18	34.2	7.5	104.1	5.7	75.3	1.4	28.9
Site 19	31.7	6.8	105.5	4.9	91.0	3.4	14.5
Average of All Sites	**20.9**	**8.7**	**113.1**	**13.2**	**73.9**	**5.6**	**39.2**

7.5.2 Evaporators

Table 7-5 presents the air measurements taken at the evaporator during cooling mode for each PAC. The average outlet humidity for all sites was about 86 percent, with a 53 °F outlet temperature. These measurements describe the cooling effect of the PAC on the room air. The average inlet temperature was about 73 °F. Site 05, Site 10, and Site 12 had relatively high outlet-inlet temperature differences (about 30 °F).

Table 7-5 Average Evaporator Inlet and Outlet Measurements

Site ID	Evaporator Outlet Relative Humidity (%)		Evaporator Outlet Temperature (°F)		Evaporator Inlet Temperature (°F)		Evaporator Outlet-Inlet Temperature Difference (°F)
	Average	StdDev	Average	StdDev	Average	StdDev	
Site 01	78.6	5.2	58.8	4.2	73.7	1.2	-14.9
Site 02	81.5	5.2	61.5	3.7	76.7	1.5	-15.1
Site 03	88.2	6.2	58.9	2.7	77.2	2.1	-18.3
Site 04	87.4	5.9	48.0	3.8	71.0	2.5	-23.0
Site 05	91.6	3.0	46.1	4.9	75.7	2.2	-29.6
Site 06	76.7	9.6	58.7	8.4	72.3	2.2	-13.6
Site 07	88.4	4.6	56.2	4.9	71.5	1.9	-15.3
Site 08	92.9	5.2	52.3	6.8	75.4	2.4	-23.1
Site 09	80.0	7.4	60.6	6.3	74.2	1.7	-13.6
Site 10	94.5	6.7	42.8	6.5	76.5	9.7	-33.7
Site 11	89.5	4.8	58.7	6.1	76.0	1.7	-17.3
Site 12	96.0	3.7	47.8	2.7	78.5	1.7	-30.7
Site 13	94.9	2.1	53.8	1.8	74.3	0.9	-20.6
Site 14	78.9	9.1	55.9	5.5	71.3	2.2	-15.4
Site 15	79.3	9.9	54.9	4.3	68.5	3.0	-13.6
Site 16	79.9	4.5	63.9	3.8	76.0	2.0	-12.1
Site 17	86.9	4.3	60.8	5.8	75.6	1.9	-14.8
Site 18	83.6	3.6	57.1	4.5	75.7	1.5	-18.6
Site 19	85.0	3.0	52.8	3.9	75.7	1.5	-22.9
Average of All Sites	**85.9**	**9.3**	**53.1**	**8.4**	**73.1**	**4.7**	**-20.0**

7.6 Annual Energy Use Model

This section describes a model developed to determine PAC annual energy use (AEU) for residential and for light commercial sites based on outdoor temperature. The model is based on the aggregated and averaged data from all residential or light commercial sites, meaning that each point represents an average value (with the exception of the data count, which provides a reference on data availability). These equations can be used to estimate an AEU for a PAC based on outdoor temperature.

7.6.1 AEU Model for Residential Sites

Figure 7-7 depicts the percentage of time a PAC spends in each operational mode as a function of outdoor temperature for the residential sites.

The data for each PAC mode were fit with a linear model to derive an equation for percentage of time spent in that mode as a function of outdoor temperature. The linear equations for time in mode are presented below. In the equations, the variable "OutTemp"[8] is the average outdoor temperature.

$$\%\,Time\ in\ Cooling\ Mode = 0.005 * OutTemp - 0.2909$$

$$\%\,Time\ in\ Fan\ Mode = 0.0005 * OutTemp - 0.0128$$

$$\%\,Time\ in\ Off/Standby\ Mode = -0.0055 * OutTemp + 1.3038$$

Because the fit coefficients were rounded, the linear fit for percentage of time in off/standby mode was not used in the AEU model. The following equation was used for the percentage of time in off/standby mode.

$$\%\,Time\ in\ Off/Standby\ Mode = 1 - \%\,Time\ in\ Cooling\ Mode - \%\,Time\ in\ Fan\ Mode$$

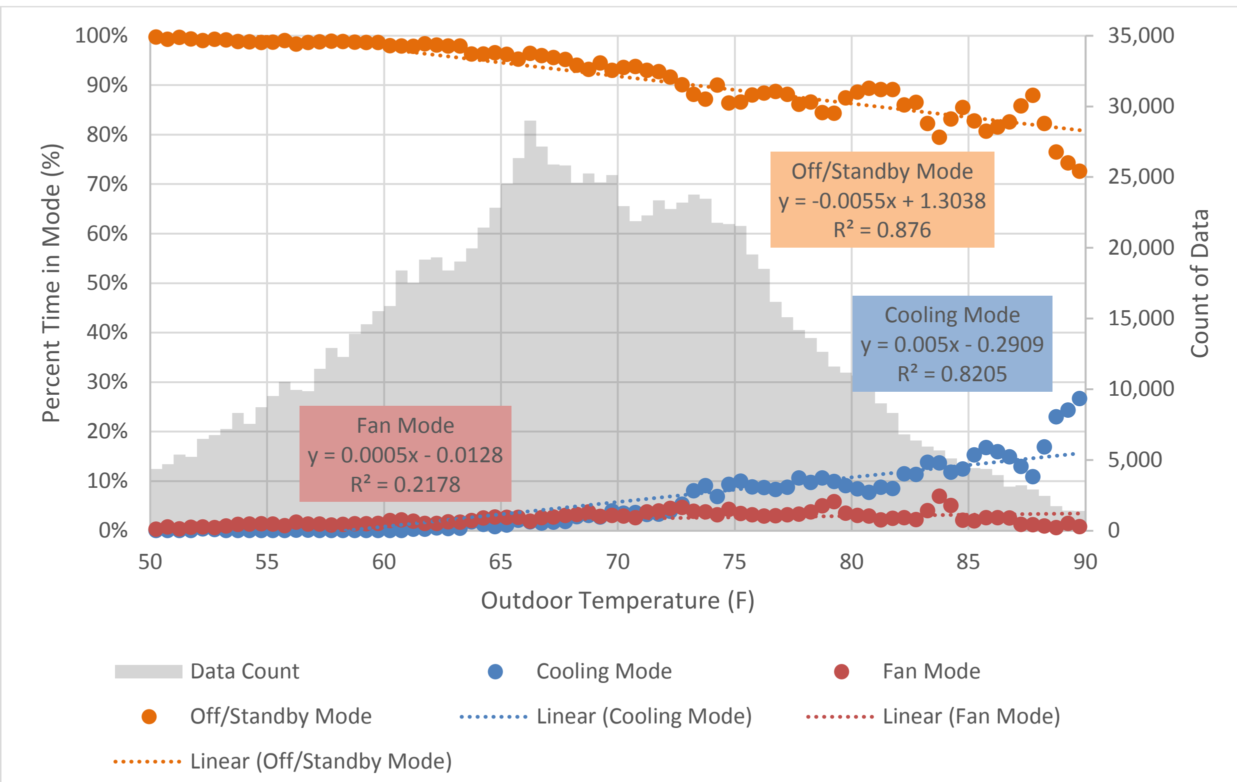

Figure 7-7 Annual Energy Use Model as a Function of Outdoor Temperature for Residential Sites

[8] For our data collection, this is the variable TWUG.

7.6.2 AEU Model for Light Commercial Sites

Figure 7-8 describes the percentage of time in each operational mode as a function of outdoor temperature for PACs at light commercial sites.

The data for the commercial sites were fit as they were for the residential AEU model described in section 7.8.1. The linear equations for time in each operational mode are presented below.

$$\%\,Time\ in\ Cooling\ Mode = 0.0193 * OutTemp - 0.9382$$

$$\%\,Time\ in\ Fan\ Mode = \ -0.0076 * OutTemp + 0.7486$$

$$\%\,Time\ in\ Off/Standby\ Mode = -0.0116 * OutTemp - 1.1896$$

The percentage of time in off/standby mode, presented above for reference only, was not used in the AEU model. Because the linear fit coefficients were rounded, using outdoor temperature in the three linear fits to calculate the percentage of time for each mode results in a total of almost but not exactly 100 percent. The remaining time that is not allocated to cooling or fan mode is allocated to off/standby mode. The equation is presented below.

$$\%\,Time\ in\ Off\text{-}Standby\ Mode = 1 - \%\,Time\ in\ Cooling\ Mode - \%\,Time\ in\ Fan\ Mode$$

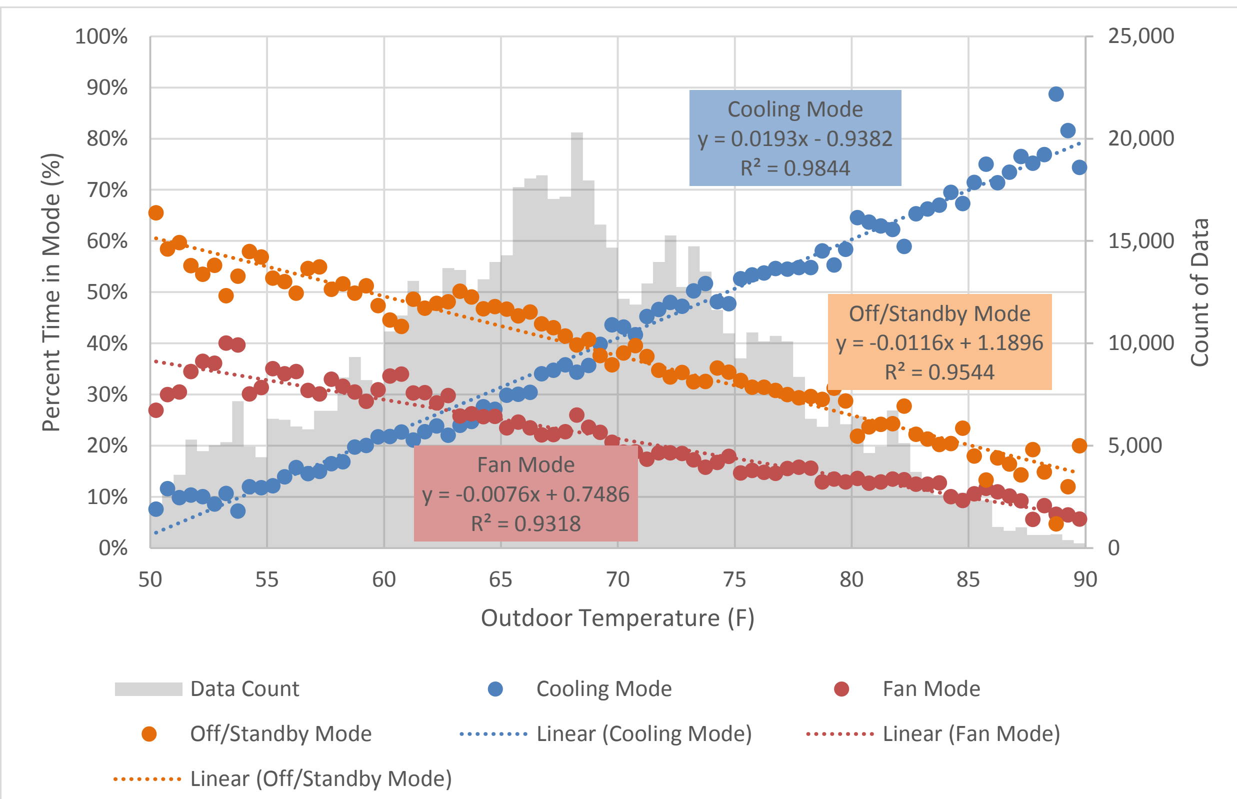

Figure 7-8 Annual Energy Use Model as a Function of Outdoor Temperature for Commercial Sites

7.6.3 *Example of AEU Calculation*

This section presents an example of a calculation of PAC AEU using average monthly outdoor temperatures for a residential site. Table 7-7 lists the results from the residential model calculation of percentage of time in different modes. Using estimated average outdoor temperatures for each month, the percentage of time in each mode is calculated.

Table 7-6 Calculation of Average Temperature and Percentage of Time in Mode by Month

Month	PAC In Use?	Average Outdoor Temp (F)	Time Cooling Mode (%)	Time Fan Mode (%)	Time Off-Standby Mode (%)
Jan – June	No				
Jul	Yes	69.16	5.5	2.2	92.3
Aug	Yes	71.48	6.6	2.3	91.1
Sep	Yes	66.47	4.1	2.0	93.8
Oct	Yes	59.83	0.8	1.7	97.5
Nov – Dec	No				

The cooling mode power can be calculated in W based on the PAC capacity (in Btu/hr) and EER (in Btu/hr per W). The calculated cooling mode power, combined with an estimated power for fan mode and off/standby mode, can be input into the AEU model to calculate the annual energy use in kWh. Table 7-8 shows example input parameters for calculating the cooling mode power. Table 7-9 presents the calculated cooling mode power in watts (capacity/EER), as well as example values for fan mode and off/standby mode power.

Table 7-7 Example Input Parameters

Input Parameter	Value
Capacity (Btu/hr)	8,000
EER (Btu/hr per watt)	7

Table 7-8 Example Power for Each Mode of Operation

Mode	Power (W)
Cooling	1,143
Fan Only	100
Off/Standby	2.4

The equation used to develop monthly power consumptions is:

$$Monthly\ Power\ (kWhr) = 730\ hr * (\%CoolingMode * CoolingModePower + \%FanMode * FanModePower + \%Off/StandbyMode * Off/StandbyPower)/1{,}000$$

The monthly power consumption equation assumes that there are 730 hours in a month (8,760 hours per year/12 months). Using the equation described above along with the percentage of time in modes and power for each mode, the monthly power consumption (in kWh) can be calculated. The results of a sample calculation are presented for only the months used in Table 7-10. It should be noted that the AEU presented below is based on metered average outdoor temperatures (which were reportedly lower than usual for most summers) and only for the four months that were metered. It is believed that PAC owners may operate the units in earlier months (May and June), if temperatures are high, which would contribute to higher annual energy use.

Table 7-9 Sample AEU calculation results

Month	Monthly Power (kWh)
Jul	49.02
Aug	58.75
Sep	37.71
Oct	9.86
AEU:	155.33

8 CONCLUSIONS

Data from our field study enabled us to develop relationships between PAC operation and outdoor temperature. We developed two models to reflect the different operational requirements of residential and light commercial settings. On average, PACs at commercial sites may operate in cooling mode for longer periods than did those at residential sites (34.75 percent versus 4.08 percent). To confirm this assumption, further testing would need to be performed.

A study conducted by *Consumer Reports*[9] found that PACs tested in a 250-square-foot room struggled to provide adequate cooling that met the unit's temperature set point. In cases where a PAC can meet the cooling loads of a room adequately, a higher-capacity unit would reduce the hours of operation in cooling mode. If the unit cannot handle the cooling load, field-metering data indicate the PAC will remain in cooling mode until a user turns the unit off.

[9] *Consumer Reports*. "Are portable air conditioner claims a lot of hot air?" http://www.consumerreports.org/cro/news/2014/06/are-portableair-conditioner-claims-a-lot-of-hot-air/index.htm. Published online June 12, 2014. Last accessed December 8, 2014.

Additional field monitoring would improve the analysis and models described in this report. Longer monitoring periods in different geographical regions also would provide greater insight into the operation and characteristics of PAC usage.

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